Dynamics of Coarse Woody Debris—A Simulation Study for Two Southeastern Forest Ecosystems

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Abstract

The FORCAT gap model was used to simulate formation and decomposition of coarse woody debris (CWD) for two forest ecosystems on the Cumberland Plateau in east Tennessee. Simulations were conducted for 200 years after clearcutting on a total of 100 plots, 1/12 ha in size. Model results showed a decrease in CWD loads in early years as logging slash decomposed. After year 32, CWD loads increased rapidly and peaked around year 90. Coarse woody debris loads in older stands gradually decreased through the remainder of the simulation period. The assumed decomposition rate strongly influenced CWD loading. Model results correspond closely to observed loadings in old-growth stands on the Cumberland Plateau.

Introduction

While exact effects are not well documented, few doubt the ecological importance of coarse woody debris (CWD) in Southeastern ecosystems. Little is known, however, about the changes in CWD loads that might be expected over long periods, such as through succession. Most studies in the Southeast have provided short-term "snapshots" of CWD for specific successional stages and have looked at old-growth stands (MacMillan 1988; Muller and Liu 1991; Smith and Boring 1990).

Coarse woody debris dynamics are difficult to predict because inputs and losses are affected by many biotic and abiotic factors. Inputs are determined by species composition, site quality, and sizes and types of disturbance. Losses of CWD are affected by management strategies and decomposition rates. Several studies show that decomposition rates depend on multiple factors including species (Harmon 1982), climate (Muller and Liu 1991), site (Abbott and Crossley 1982), size of material (Mattson and others 1987), and contact with the ground (Barber and Van Lear 1984).

Van Lear (1996) discusses current research on CWD dynamics in the Southeast elsewhere in these proceedings, so I cite only a few studies here. A study conducted in western Oregon and Washington provides the most complete description of long-term CWD dynamics to date. Spies and others (1988) and Spies and Cline (1988) described CWD loading in 196 Douglas-fir, *Pseudotsugc menziesii* (Mirb.) Franco, stands across a chronosequence ranging from 40 to 900 years since disturbance. This work serves as a comparison for my simulation study, so I will provide its results in some detail.

Loading of CWD over the 900-year chronosequence was described for five successional stages: stand initiation, st exclusion, understory reinitiation, old growth, and clima: During the stand initiation stage (lasting 20 to 30 years), accumulation of CWD was slow (fig. 1). Even though tr mortality was high during this period, most trees were to small to be considered CWD. Coarse woody debris inpu began during the stem exclusion period (lasting 10 to 30 years) as the canopy closed and mortality of larger trees began. Input rates were relatively low during this period because many dying trees were small. Canopy dominan diminished during the understory reinitiation stage (lasti 100 to 150 years), allowing understory herbs, shrubs, an trees to become established. Mortality of some large tre began during this period and CWD accumulated rapidly.

Coarse woody debris continued to accumulate rapidly during the old-growth stage (lasting 500 to 800 years) a natural disturbances such as windthrow, diseases, and insects increased mortality rates of large trees (fig. 1). Much of the mortality during this period was among dominant shade-intolerant species, which were replaced shade-tolerant species. The shade-tolerant species were

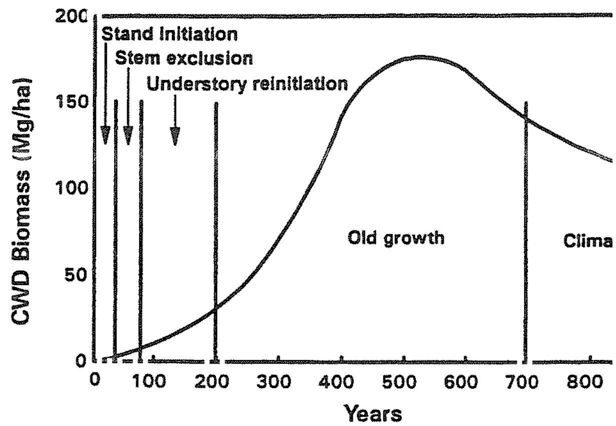

Figure 1—Accumulation of coarse woody debris across a 900-year chronosequence for ecosystems of western Oregon and Washington (Sp and Cline 1988).

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relatively long lived and contributed little CWD during the later years of the old-growth stage. Late in the old-growth stage, decomposition began to exceed inputs and CWD loading decreased.

The climax stage was reached when all shade-intolerant species were replaced by shade-tolerant species (fig. 1). This stage had less CWD than the old-growth stage because it lacked the original overstory dominants. Coarse woody debris dynamics during this stage were difficult to describe because few of these stands existed. Usually, by this time, either natural or anthropogenic disturbance had reinitiated succession.

A lack of similar information about long-term CWD dynamics in Southeastern ecosystems prompted the simulation study described in this paper. I used a previously developed model of forest succession to simulate stand dynamics, and I estimated CWD loading from predicted tree mortality. My objectives were to provide basic information on long-term CWD dynamics in Southeastern ecosystems and to identify information gaps.

Methods

Description of the Model

The model used for this study was FORCAT (FORests of the CAToosa Wildlife Management Area), which was developed for mixed-species forests on the Cumberland Plateau in east Tennessee (Waldrop and others 1986). Although the major reason for selecting FORCAT was my familiarity with the model, it is one of only a few existing models capable of simulating long-term stand dynamics for managed, mixed-species stands (Waldrop and others 1989).

FORCAT is a member of a family of models based on the widely used FORET model (Shugart and West 1977). FORET is described by Shugart (1984) as a spatial gap model that simulates stand dynamics for the forests of east Tennessee. Gap models are a special case of single-tree models and have demonstrated adaptability over a wide range of forest types. Simulated gaps range from 0.04 to 0.08 ha in size (Shugart and West 1979), approximating the area opened by the death or removal of an individual canopy tree (Shugart and West 1980). These models generally use simple equations, with parameters that are easily obtained, to approximate the mechanisms that cause a forest to change on a small plot of land. Such changes are simulated through the birth, growth, and death of individual trees as controlled by various measures of competition and other environmental stress factors. Variables used in gap models as environmental stress factors include shade, stand basal area, soil moisture, and ambient temperature.

The FORCAT model was developed through numerous modifications to FORET, making it more specific to managed sites on the Cumberland Plateau (Waldrop and others 1986). The model simulates stand dynamics on a 0.08-ha plot using 30 hardwood and 3 pine species commonly found in the region. Simulation begins with a mature stand, which is immediately clearcut. After clearcutting, sprouts and seedlings are stochastically added to simulated plots based on silvical characteristics of each species. Diameter and height growth are calculated each year for each tree as a function of site, species, competition, and environmental stress. Trees are killed stochastically each year based on age, species, and current growth rates.

Some of the more significant changes to FORET that were included in FORCAT were: (1) beginning the simulation with natural regeneration found in clearcuts instead of bare ground, (2) basing growth rates on site quality and local climate, (3) basing seed availability and sprouting habit on species-specific characteristics, and (4) simulating periodic clearcutting and prescribed burning. FORCAT was developed and tested for a xeric hardwood site and validated with data from a nearby mesic oak site.

Many of the growth and mortality equations used in FORCAT and FORET were adapted from the JABOWA model for northern hardwoods (Botkin and others 1972). Shugart and West (1977), Shugart (1984), and Botkin (1993) described those equations in detail. Shugart (1984) also discussed gap models at length. Waldrop (1983) and Waldrop and others (1986) described development and validation of FORCAT.

Modeling Coarse Woody Debris Dynamics

Few changes to FORCAT were required to predict CWD loading. In FORCAT, the diameter at breast height (d.b.h.) of each tree on the simulated plot (up to 1,200 trees in young clearcuts) is updated each year according to growth calculations and then stored in an array. If a tree dies in any year, the d.b.h. of that tree is removed from the storage array. At that point, the dead tree was considered CWD and its biomass was estimated. Biomass was estimated for both stems and crowns using d.b.h. as the independent variable in regression equations given by Clark and others (1986). To account for limbs too small to be considered CWD (diameter less than 10 cm), estimated crown biomass was reduced by 20 percent.

The total biomass of dead stems and crowns on a plot was calculated for each year. This amount was added to the total CWD remaining from the previous year, and the new sum was reduced by a constant rate to allow for decomposition. Decomposition rates of 6 percent, 8 percent, and 10 percent were used to examine the differences these rates caused in CWD accumulation. These decomposition rates roughly follow those reported by Harmon (1982) for hardwood species.

Stand dynamics and CWD accumulation were simulated for the two site types (xeric and mesic) that were used to develop and validate FORCAT. The results of these simulations should give some insight into the effect of site productivity on CWD accumulation. Model input for the xeric site was data from a stand with a basal area of 19.3 m^2/ha and dominated by post oak (*Quercus stellata* Wangenh.), southern red oak (*Q. falcata* Michx.), and scarlet oak (*Q. coccinea* Muenchh.) (table 1). The xeric site was characterized by thin, acidic soils and moderate topography. It had a site index of 18 m for upland oaks (base age 50). For the mesic site, basal area of commercial-sized trees was 17.6 m^2/ha and species composition was mostly chestnut oak (*Prinus* L.), white oak (*Q. alba* L.), northern red oak (*Q. rubra* L.), and yellow-poplar

Table 1—Species composition for xeric and mesic sites used as input to FORCAT

Species	Xeric site	Mesic site
	Total basal area (pct)	
Black oak	10.6	4.5
Chestnut oak	--	24.6
Northern red oak	--	18.6
Post oak	27.0	--
Scarlet oak	27.2	--
Southern red oak	13.5	--
White oak	4.0	22.1
Other oaks	1.4	--
Hickories	3.1	11.8
White ash	--	3.9
Yellow-poplar	--	11.6
Other hardwoods	7.0	2.9
Virginia pine	6.2	--

(*Liriodendron tulipifera* L.). The mesic site had a north aspect, moderate to steep slopes, and a site index of 31 for yellow-poplar (base age 50).

Simulations began with mature stands, which were immediately clearcut. No artificial regeneration or site preparation was allowed. A simulation period of 200 ye after clearcutting was used for each of 100 simulated 1/ ha plots. Due to the stochastic nature of the growth and mortality calculations, no two simulated plots were identical. Shugart and West (1979) suggested including 100 plots in simulations to account for the variability fo in most Southeastern forest types.

Several limitations to this approach of modeling CWD accumulation are recognized. By defining CWD as dea trees, standing CWD cannot be distinguished from dow CWD. Also, CWD estimates are likely to be low becau inputs from limbs that die and fall to the ground are not included. Another limitation is that decomposition rate assumed to be the same for all species and size classes CWD and across all successional stages. Published decomposition rates were not available for the species a types of sites that FORCAT simulates. The simulations not include CWD inputs from natural disturbances or fr anthropogenic disturbances, other than the initial clearc

Results and Discussion

Coarse Woody Debris Dynamics After Clearcutting

On the xeric site, simulated regeneration was dominate sprouts of oak species (39 percent of all stems) that we abundant in the preharvest stand. Understory hardwoo that sprout prolifically, such as dogwood (*Cornus flori* L.) and sourwood (*Oxydendron arboreum* L.), made up another 30 percent of the regeneration. Pine seedlings represented less than 1 percent of the regeneration. Throughout the simulation period, understory hardwoo gradually declined in importance while scarlet oak, pos oak, and southern red oak eventually dominated the sta

For the mesic site, simulated regeneration was dominat by northern red oak, white oak, hickories (*Carya* sp.), ash (*Fraxinus americana* L.), and blackgum (*Nyssa sylvatica* Marsh.). No pine regeneration was predicted. the end of the simulation, the stand was dominated by northern red oak, chestnut oak, white oak, and yellow-po The patterns of CWD accumulation predicted by FOR (fig. 2) for xeric and mesic sites (using a 6-percent decomposition rate for both sites) were similar to the c proposed by Spies and Cline (1988) for western Oregon and Washington (fig. 1). In all three systems, this pattern resembled a bell-shaped curve that peaked during the first half of their respective periods (100 years for simulated xeric and mesic sites, 450 years for measured Douglas-fir stands). Later, CWD in each system gradually decreased until a point, late in succession, where an equilibrium between inputs and decomposition may have been reached.

Coarse woody debris accumulation on both simulated sites remained low for 30 to 40 years as trees grew to the minimum size for CWD (10 cm), even though there was significant mortality during this period (fig. 2). Between years 30 and 75 CWD increased rapidly for both simulated sites. FORCAT predicted decreases in stand basal area during this period as crown closure occurred and a few large trees began to die. On the xeric site, for example, predicted stand basal area decreased from 19.3 m^2 per ha at year 50 to 15.9 m^2 per ha at year 100.

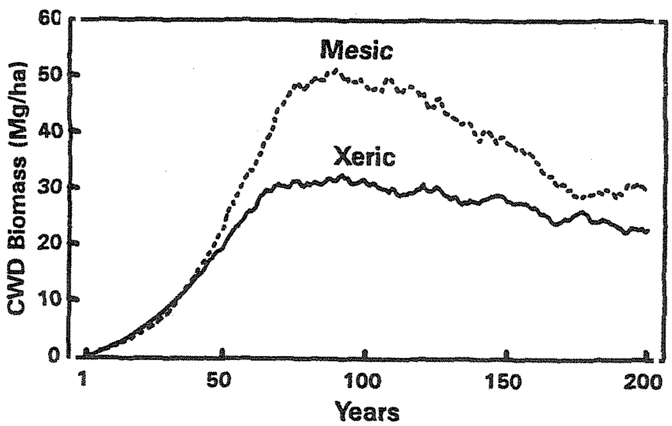

Figure 2—Accumulation of coarse woody debris for xeric and mesic sites as predicted by FORCAT (6-percent decomposition rate for both sites).

The period of rapid CWD accumulation on the xeric site lasted until the stand was about 70 years old (fig. 2) when CWD was 30.6 Mega grams per hectare (Mg/ha). Coarse woody debris continued to accumulate, but at a slower rate, to a maximum of 32.5 Mg/ha at year 91. For the remainder of the 200-year simulation period, decomposition slightly exceeded inputs and CWD loads gradually decreased.

Tree growth on the simulated mesic site exceeded that on the xeric site, producing a more rapid rate of CWD accumulation (fig. 2). On this site, CWD accumulated rapidly from years 30 through 75, reaching a total of 49.3 Mg/ha. Maximum CWD loading during the simulation period was 51.4 Mg/ha in year 89. Between years 90 and 200, CWD loading decreased much more rapidly than on the xeric site. Species on the mesic site were longer lived than those on the xeric site and the trees continued to grow. Mortality was higher on the xeric site during this period due to moisture stress. Therefore, CWD inputs were less on the mesic site than on the xeric site.

FORCAT predictions for CWD accumulation in older stands were similar to the ranges observed by Muller and Liu (1991) for old-growth stands on the Cumberland Plateau. Between years 90 and 200 (roughly equivalent to the age of old-growth stands), CWD loads on the simulated xeric site ranged from 22.8 to 32.5 Mg/ha (fig. 2). Muller and Liu (1991) reported accumulations ranging from 22 to 32 Mg/ha on dry sites including ridgetops, upper slopes, and south-facing and west-facing midslopes. Older stands on the simulated mesic site had CWD loads ranging from 30.0 (year 200) to 51.4 Mg/ha (year 90). Muller and Liu (1991) found CWD loads ranging from 34 to 49 Mg/ha on moist midslopes with a north or east aspect.

Even though FORCAT accurately predicted more CWD input on the mesic site than on the xeric site, the periods of accumulation (years 30 through 90) were nearly identical. This may indicate a failure of the model. I expected CWD loading to peak higher and later on the mesic site than on the xeric site because the species on the mesic site grow larger and are longer lived. A common problem among mixed-species models is an inability to simulate competition of different species across sites of varying quality. Since FORCAT development was based on xeric sites, its growth parameters for mesic sites may not be as accurate.

Logging Debris

An important, but so far neglected, component of CWD dynamics in managed stands is logging debris. For example, Sanders and Van Lear (1988) found that CWD after clearcutting in the Southern Appalachians can be as much as 90 Mg/ha. This debris provides regenerating stands with a structure that can be important habitat for small mammals (Evans and others 1991; Loeb 1996) as well as a source of nutrients (Mattson and others 1987).

Logging slash was added to model projections of CWD inputs immediately after simulated clearcutting. Total CWD loading at that time was assumed to equal the biomass of crowns from harvested trees. Crown biomass was estimated by using the d.b.h. of each harvested tree (xeric and mesic sites) as the independent variable in regression equations given by Clark and others (1986). These estimates were reduced by 20 percent to account for the portions of crowns too small to be considered CWD (< 10 cm in diameter).

The estimated CWD load immediately after clearcutting was 49 Mg/ha on the xeric site and 69 Mg/ha on the mesic site (fig. 3). On both sites, these levels were higher than at *any other time during the 200-year simulation period.* Figure 3 illustrates the importance of selecting site-preparation techniques that leave some CWD. Logging debris decomposes rapidly in clearcuts, but it provides some CWD during a period when there is little input. In my model, decomposition exceeded inputs through year 32. At that time CWD, totaled 16.9 Mg/ha on the xeric site and 18.3 Mg/ha on the mesic site (assuming a uniform decomposition rate of 6 percent). By year 32, all logging slash had decomposed. Therefore, after year 32 these curves were identical to those without logging slash (fig. 2).

Variable Decomposition Rates

An assumption used until now is that decomposition rates were uniform across site types. The work of Abbott and Crossley (1982) indicates that decomposition rates are higher on moist sites. By assuming a decomposition rate of 8 percent on the mesic site and 6 percent on the xeric site, the difference in simulated CWD loads between sites was greatly reduced (fig. 4). Even though CWD loading was much higher on the mesic site in year 1, it decomposed to a smaller amount than the xeric site by year 32 (12.3 present vs. 16.9 Mg/ha). By year 75, CWD was again greater on the mesic site. Beyond that point, however, the lines converged. During the last 50 years of the simulation, CWD loads on the two simulated sites were nearly identical.

This comparison (fig. 4) illustrates the observation of Abbott and Crossley (1982) that differences in decomposition rates between sites can be more important than differences in sizes of CWD. Even though the mesic site produced far more CWD biomass than the xeric site, the relatively small difference in decomposition rates (8 vs. 6 percent) produced similar CWD loading throughout the 200-year simulation. If the difference in decomposition rate is larger (10 percent vs. 6 percent), CWD loading can be greater on the xeric site for most of the simulation period (table 2).

Muller and Liu (1991) suggested that CWD loading wa: function of regional temperature patterns. Their measurements on dry sites correlated well with publishe estimates from warm Temperate Zone deciduous forests Likewise, their CWD measurements on moist sites correlated well with published estimates from cool fore: Muller and Liu (1991) observed higher CWD loads on ((moist) sites than on warm (dry) sites, suggesting that decomposition rates were not higher on moist sites or tl higher productivity on moist sites compensated for high *decomposition rates.* Broad-scale relationships, such a: this, are oversimplified because CWD decomposition o any given site is controlled by a combination of moistu temperature, soil fertility, species, size, and any numbe other factors.

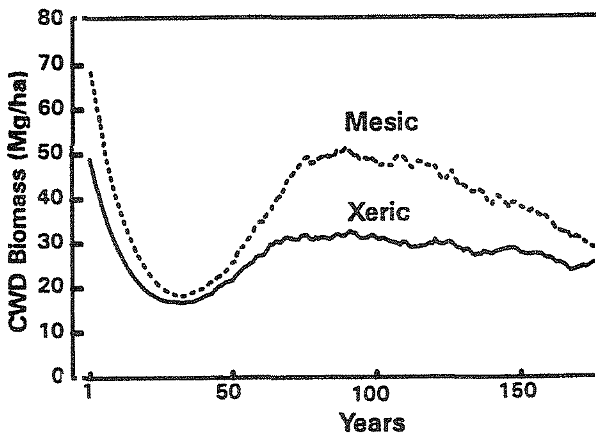

Figure 3—Dynamics of coarse woody debris after clearcutting xeric : mesic sites (predicted by FORCAT using a 6-percent decomposition : for both sites).

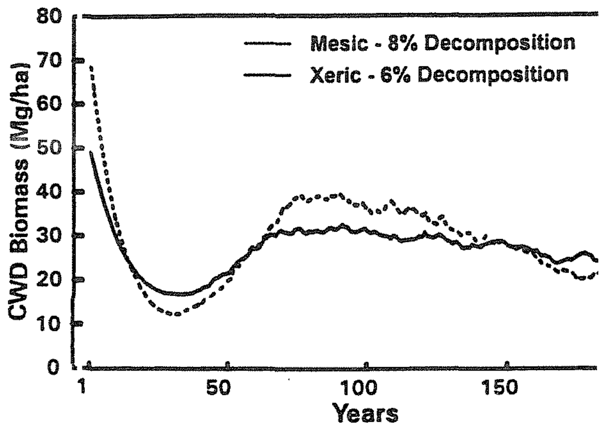

Figure 4—FORCAT projections of coarse woody debris loads by sit and decomposition rate.

Table 2—Coarse woody debris accumulation by site and decomposition rate as predicted by FORCAT

Site	Decomposition rate		
	6 pct	8 pct	10 pct
	----------	*Mg/ha*	----------
Xeric			
Year 1 (after clearcutting)	49.0	49.0	49.0
Year 32 (minimum CWD load)	16.9	11.8	8.5
Year 91 (maximum CWD load)	32.5	24.5	19.6
Year 200 (end of simulation)	22.8	16.5	12.9
Mesic			
Year 1 (after clearcutting)	68.9	68.9	68.9
Year 32 (minimum CWD load)	18.3	12.3	8.9
Year 89 (maximum CWD load)	51.4	39.8	32.3
Year 200 (end of simulation)	30.0	22.4	17.9

Conclusions

The FORCAT gap model worked well for this preliminary attempt to simulate CWD dynamics in two types of Southeastern ecosystems. Model results were similar to those of two field studies. The pattern of CWD accumulation predicted by FORCAT was similar to that observed in Western ecosystems (Spies and Cline 1988). Also, the predicted CWD loads were nearly equal to those reported by Muller and Liu (1991) for ecosystems similar to those simulated by FORCAT.

Results of this study show general trends of CWD accumulation over seral stages for the two Southeastern forest ecosystems used in the study. The result of this study shows the importance of leaving CWD after harvesting and emphasize that differences in decomposition rates (possibly due to differences in site productivity) can significantly affect CWD loading. Due to a number of limitations, however, model projections should not be considered accurate predictions of CWD loading at any given age.

A major limitation found in this study was the lack of information on inputs and decomposition rates for different tree species, sizes of CWD, and types of sites. Other knowledge gaps were discussed by Van Lear (1995) at this workshop, including the relationship of CWD inputs to natural and anthropogenic disturbance. Some of this missing information could be supplied by additional research and a broader modeling effort. For example, CWD dynamics after natural disturbances such as tornados or ice storms could be predicted by gap models if the return frequency of those disturbances was known. Also, CWD inputs from management activities such as thinnings or selection harvests could be predicted. This effort would allow managers to use model projections to help determine how to alter the level or timing of their activities to better meet their goals for CWD.

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